SAFETY EVALUATION OF FORWARD OBSTACLES COLLISION AVOIDANCE SUPPORT SERVICE USING DRIVING SIMULATOR

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SUMMARY

Various warning systems are being studied in the world to improve traffic safety. To enhance the information/warning systems, systems that are based on sensors installed on the roadside are under research. The system informs the driver of the traffic condition through the in-vehicle display and/or the roadside message board. We have evaluated effectiveness and risk of the forward obstacles collision avoidance support system using the driving simulator (DS) in Japan Automobile Research Institute (JARI). As a new evaluation criteria of the effectiveness the velocity at 100m ahead the obstacle was introduced that is able to show the difference of effectiveness of each type of information more clearly. The evaluation results shows that the forward obstacles collision avoidance support system is effective, especially when using the combination of the in-vehicle and the roadside massage information. Next, as a new evaluation method for system risk the driver-system integrated erroneous operation probability model was introduced. The result shows that the accident reduction ratio is 86%.

INTRODUCTION

Various warning systems are under research to improve traffic safety, and several systems such as Forward Vehicle Collision Warning Systems and Lane Departure Warning System have been introduced into the market already. These systems are based on onboard sensors, which means that onboard sensors detect traffic environment around the host vehicle and inform the driver of dangerous situation. But, it is impossible for these systems to detect hidden obstacles such as an obstacle on the curve road ahead. To enhance the information/warning systems, systems that are based on sensors installed on the roadside are under research. The system informs the driver of the traffic condition through the in-vehicle display and/or the roadside message board. These systems are called ‘Cooperative Information/Warning System’.

When evaluating cooperative systems, the system should be evaluated from two major points of view. One point of view is effectiveness because the purpose of the system is to reduce the number of accidents. Another point of view is safety or risk because false information generated by errors of traffic recognition sensors might give unsafe influence to the driver’s judgments.

Concerning the evaluation of the effectiveness of onboard systems, the response time to an event such as the warning is usually used. Figure 1 shows a test result of Forward Vehicle Collision Warning Systems [(1)] . In the case of onboard systems the driver is able to recognize traffic situation simultaneously when the warning is issued. On the contrary, in the case of roadside sensor based systems, when the information/warning is issued, the driver is not able to recognize the obstacle yet because the obstacle is hidden on the curve road ahead. Consequently, another new evaluation criteria should be applied to evaluate the roadside sensor based systems

Concerning the evaluation of the safety or risk of the system we do not have appropriate method. Consequently, new evaluation criteria should be invented to evaluate the safety or risk of the system.

We evaluated the effectiveness of cooperative system, especially the forward obstacles collision avoidance support system using the driving simulator (DS) in Japan Automobile Research Institute (Figure 2), and also evaluated the safety/risk of the system using the driver-system integrated erroneous operation probability model.

In the paper test method, test results including driver's speed reduction characteristics, workload reduction, and the evaluation result of the safety/risk are described.

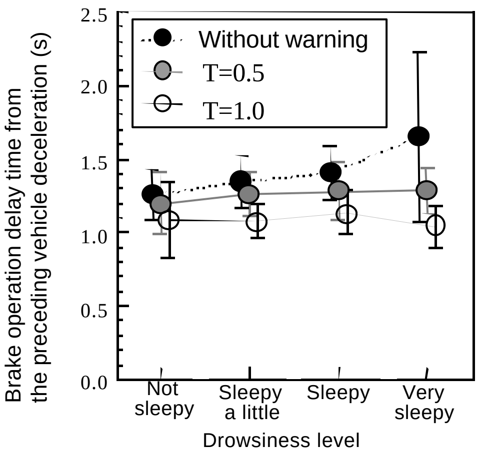

Figure 1 A test result of Forward Vehicle Collision Warning System

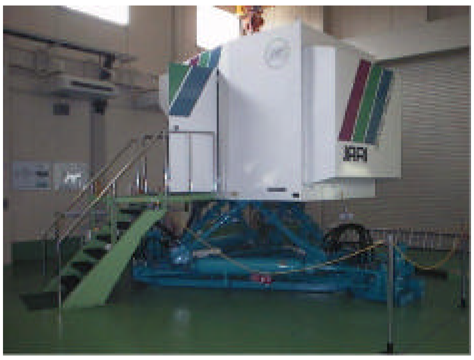

Figure 2 JARI Driving Simulator

TEST METHOD

To evaluate information/warning systems validly the test method is important. Test scenario, information providing manner and test procedure will be introduced at first.

Test Senario

<u>Test Course</u> A simple test course with four corners was designed. Figure 3 shows the test course on DS. The details are as follows.

- The course has two lanes.
- Each curve radius is 250m.
- An obstacle vehicle is placed on the curve, at 150m behind the curve entrance.

  In this case the visibility distance of the driver is about 80m, which means the driver can find the obstacle vehicle at the point about 80m ahead the obstacle.

  - Vehicles on the adjacent lane are arranged.
  - The curve information is provided when an obstacle is not on the curve, and the obstacle information is provided when an obstacle is on the curve. The detail of the information is described in the following section.
  - Data obtained at the two corners which have same curve radius such as the corner 2 and 3 are not distinguished when data processing.

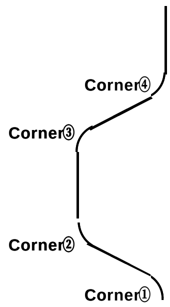

Figure 3 Configuration of the test course

<u>Test condition</u>

- The number of test driver is twenty including male and female drivers of various ages.
- Each driver is instructed to drive at about 120km/h on the straight course and drive at safe speed on the curve reducing the vehicle speed.
- Mental arithmetic is loaded to the driver as driving workload in some test cases. When simple series numbers with 5s interval are read aloud, the driver have to answer by adding a new number to the previous one.

Ex. Question:5-5-7-8 (interval is 5s)
Answer:10-12-15

- Each driver informs the test conductor of his/her subject evaluation result for each information providing type.

Information Providing Manor

To evaluate effectiveness of infrastructure based system various types of information providing manor were tested.

<u>Information Providing Points</u> Figure 4 shows the information providing points. The in-vehicle information is provided at points, P1 and P2 using the visible and audible display. The points, P1 and P2 vary according to the vehicle speed. The roadside message is provided at points, P1' and P2' using variable message boards. The detail is as follows.

P1: when the driver starts decelerating at 1.0 m/s^2 from P1, the vehicle stops in front of the obstacle.

EX. P1 is 556m ahead the obstacle when the vehicle speed is 120km/h.

P2: when the driver starts decelerating at 2.0 m/s^2 with 1.0s delay time from P2, the vehicle reduces the speed to 80km/h on 80m ahead the obstacle.

EX. P1 is 268m ahead the obstacle when the vehicle speed is 120km/h.

P1': 386m ahead the obstacle.

P2': 180m ahead the obstacle.

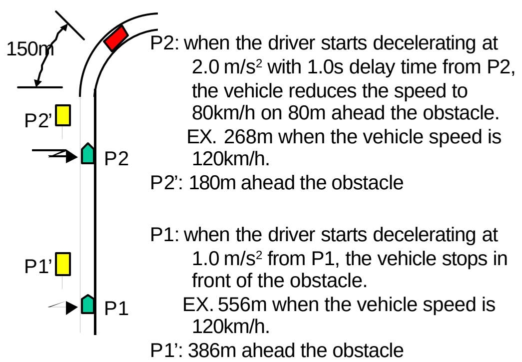

Figure 4 Information providing points

<u>In-vehicle Information and Roadside Message</u> Figure 5(a) shows the in-vehicle information. The in-vehicle information includes visible and audible display. Figure 5(b) shows the roadside message. The difference between the information 5 and 6 is whether the message is blinking or not. The message of the information 5 is blinking to enhance driver's atention.

No.	Visual display	Audible display	Position
Information①	この先カーブ Sharp curve ahead	Pi Pi Sharp curve ahead	P1
Information②	停止車あり Stop vehicle ahead	Pi Pi Stop vehicle ahead	P1
Information③	停止車注意 Be careful, Stop vehicle ahead	Pi Pi Pi Pi Be careful, Stop vehicle ahead	P2

(a) In-vehicle information

No.	Road side message at P1'	Road side message at P2'
Information④	この先カーブ Sharp curve ahead	カーブ注意 Be careful, Sharp curve ahead
Information⑤	この先停止車両 Stop vehicle ahead	Message is blinking 停止車両注意 Be careful, Stop vehicle ahead
Information⑥	この先停止車両 Stop vehicle ahead	Message is not blinking 停止車両注意 Be careful, Stop vehicle ahead

(b) Roadside message

Figure 5 In-vehicle information and roadside message

<u>Information Types</u> To evaluate effectiveness of information several types of information were chosen, in-vehicle type, roadside type and cooperative type including without information. Table 1 shows the information/message types chosen for the test. Each type is a standalone or combined information out of the information in Figure 5.

Table 1 Information types

Type	Purpose	In-vehicle		Roadside
		P1	P2	P1' and P2'
Type 0	Curve /Obstacle	-	-	-
Type 1	Curve	Information 1	-	-
Type 2	Obstacle	Information 2	-	-
Type 3	Obstacle	Information 2	Information 3	-
Type 4	Curve	-	-	Information 4
Type 5	Obstacle	-	-	Information 5
Type 6	Obstacle	-	-	Information 6
Type 7	Curve	Information 1	-	Information 4
Type 8	Obstacle	Information 2	Information 3	Information 5
Type 9	Obstacle	Information 2	Information 3	Information 6

Test Procedure

All test cases for each subject driver are shown in Table 2. No. 1 and No. 2 are only for practice. Tests from No. 3 to No. 6 are taken for the base data without information. Tests from No. 7 to 15 are data on the right turn corner, which are mainly used for data analysis. Tests from No. 16 to 19 are taken for supplemental data. Test No. 20 and 21 with mental arithmetic are taken to evaluate driver's workload. No. 22 is taken to analysis driver's behavior to a false information that means that an obstacle information is issued even when an obstacle does not exist really. No. 23 is taken to analysis driver's behavior to a missing information which means that a curve information is issued even when an obstacle does exist really.

The test procedure is as follows.

(1) The subject driver does practice to be familiar with DS at first.

(2) Tests from No. 3 to No. 6 are taken to obtain the base data without information.

(3) Tests from No. 4 to No. 22 are taken for data analysis. Tests from No. 4 to 22 are applied randomly for each subject driver.

(4) Test No. 23 is taken at last to evaluate driver's over-reliance after having got information effectiveness.

As mentioned before the instruction to the subject driver is that the subject driver should drive at about 120km/h on the straight course, reducing to safe speed on the curve according to own judgment, and applying emergency brake when the driver finds the obstacle on the road.

Table 2 Test cases

Test No.	Curve 0：250R 1：250L	Obstacle 0：with 1：without	Information type	Note
1	0	0	0	Practice
2	0	1	8	↑
3	0	0	0	Base data without information
4	1	0	0	↑
5	0	1	0	↑
6	1	1	0	↑
7	0	0	1	In-vehicle information
8	0	1	2	↑
9	0	1	3	↑
10	0	0	4	Roadside message
11	0	1	5	↑
12	0	1	6	↑
13	0	0	7	Cooperative information
14	0	1	8	↑
15	0	1	9	↑
16	1	0	1	
17	1	1	2	
18	1	1	3	
19	1	1	8	
20	0	1	2	With mental arithmetic
21	0	1	8	↑
22	0	0	8	False information
23	0	1	7	Missing information

TEST RESULTS

As mentioned before in the case of roadside sensor based systems, when the information/warning is issued, the driver is not able to recognize the obstacle yet because the obstacle is hidden on the curve ahead. Consequently several evaluations of test result were examined.

Subject Test Drivers

Figure 6 shows the distribution of the subject drivers involved in this experiment test.

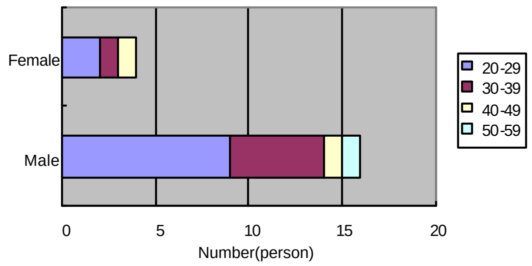

Figure 6 Distribution of subject drivers

Gas Pedal Release Timing

Figure 7 shows the gas pedal release timing. Horizontal axis is the distance to the obstacle with the standard deviation. Longer distance to the obstacle means earlier timing of the driver action. As seen in the figure the driver tends to release the gas pedal at a little earlier timing when the curve/obstacle information is offered than when no information (base data). But, the timing difference between the curve information and the obstacle information is not observed clearly.

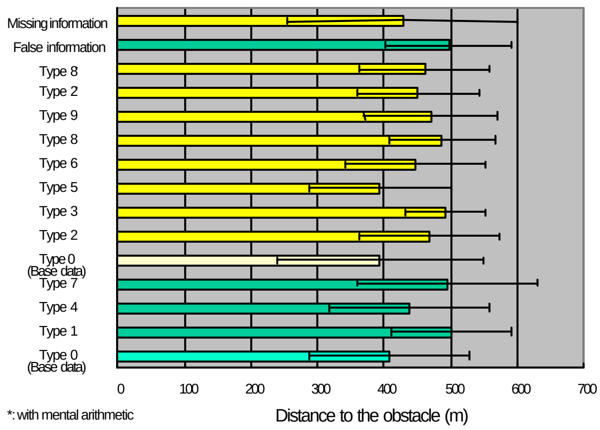

Figure 7 Gas pedal release timing

Brake Application Timing

Figure 8 shows the brake application timing. In this case the timing difference between the curve information and the obstacle information is clearly observed. The driver tends to apply the brake operation at earlier timing when the obstacle information is offered than when the curve information is offered. And the driver tends to apply the brake operation at earlier timing when the combined information with the in-vehicle and the roadside message information (Type 8, 9) is offered than when the single information (Type 2, 3, 4, 5) is offered.

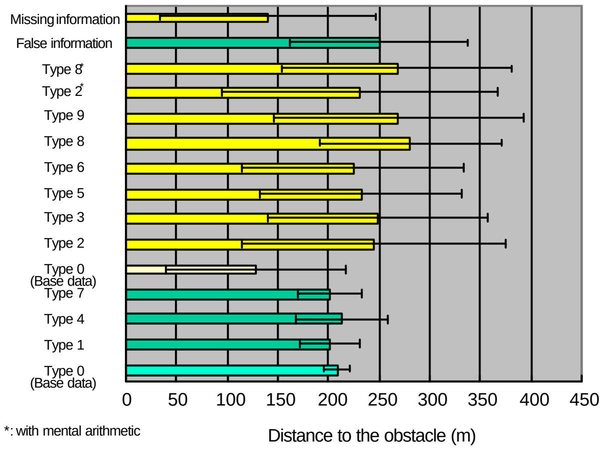

Figure 8 Brake application timing

Vehicle Speed At 100m Ahead The Obstacle

To clarify the difference of effectiveness of each information type the vehicle speed at 100m ahead the obstacle was examined. Figure 9 shows the result. The difference of effectiveness of each information type is shown more clearly. The driver reduces the vehicle speed to less than 80 km/h when the obstacle information is offered because the driver knows that he/she can stop easily at this speed when finding an obstacle. On the contrary the driver does not reduce the vehicle speed when only the curve information is offered.

As mentioned in the previous section the driver tends to reduce the vehicle speed to less speed when the combined information with the in-vehicle and the roadside information (Type 8, 9) is offered than when the single information (Type 2, 3, 4, 5) is offered.

An interesting result was observed on the vehicle speed on Type 2* and Type 8* where the mental arithmetic is set to the driver as driving workload. The vehicle speed on Type 8^* is much less than that of Type 2^*. The detail analysis will be shown in the later section.

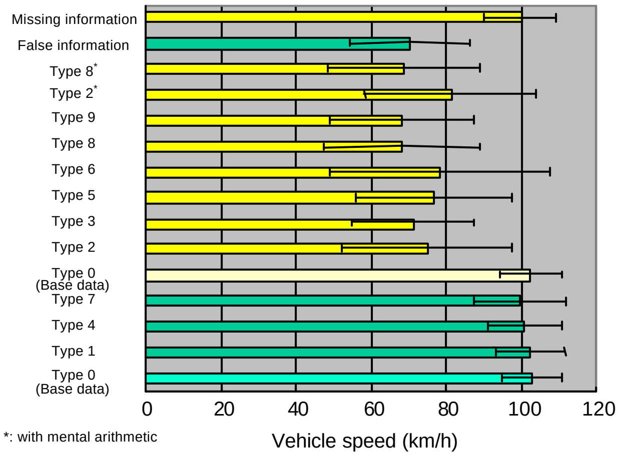

Figure 9 Vehicle speed at 100m ahead the obstacle

Subjective Evaluation

Figure 10 shows the subjective evaluation result of each information type. The combined information with the in-vehicle and the roadside information (Type 8, 9) has obtained higher point than the single information (Type 2, 3, 4, 5).

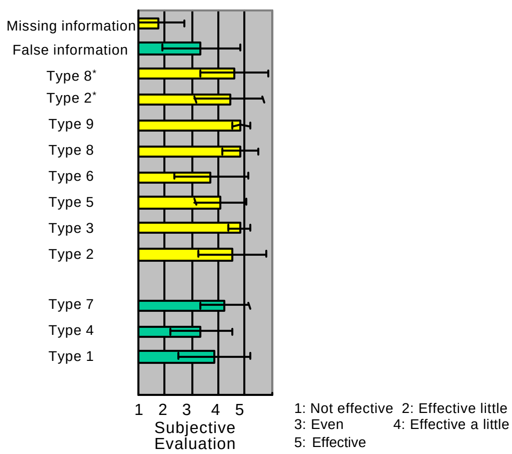

Figure 10 Subjective evaluation result of each information type

Evaluation of Driver's Workload

As mentioned before the vehicle speed on Type 8^* is much less than that of Type 2^*. Figure 11 shows the result of driver's workload evaluation. Horizontal axis is the ratio of the right answer for the mental arithmetic. Vertical axis is the vehicle speed at 100m ahead the obstacle. The right answer ratio of Type 8^* is a little better than that of Type 2^*, and the vehicle speed at 100m ahead the obstacle of Type 8^* is much less than that of Type 2^*. The result is understood as follows.

- When the driver's workload is high, the single information such as the in-vehicle information only is not well accepted by the driver because the driver is busy for the mental arithmetic.
- The combined information with the in-vehicle and the roadside information that is transferred to the driver through both audible and visual sense is well accepted by the driver.

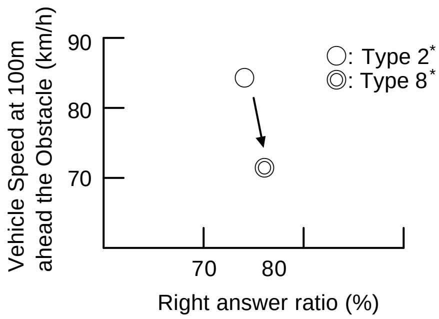

Figure 11 Driver's workload evaluation result

SAFETY EVALUATION

The effectiveness of the forward obstacles collision avoidance support system was shown up to here. The safety/risk of the system is evaluated from here.

Driver-System Integrated Error Probability Model

A driver-system integrated erroneous operation probability model that shows the combination of the driver's operation error probability and the system's false information probability is introduced first. The model makes it possible to show the effectiveness and risk of the system easily and to calculate the accident reduction ratio.

Figure 12 shows the driver-system integrated erroneous operation probability model. The model is based on the duplex model that means an accident occurs when the driver and the system cause erroneous operation simultaneously. The horizontal axis shows the driver's operation probability consisting of the erroneous operation probability and the normal operation probability. The sum of the driver's erroneous operation probability (Pm) and the driver's normal operation probability (1-Pm) is 1.0. The vertical axis shows the system's operation probability consisting of the false operation probability and the normal operation probability. The sum of the system's false operation probability (Ps) and the system's normal operation probability (1-Ps) is 1.0. Accordingly, each area in Figure 12 shows the probability when the driver and the system are in error condition or in normal condition.

Parameters in Figure 12 are explained below.

P_m: Erroneous operation probability of the driver before introducing the system

P_s : False operation probability of the system

P_{m1}: Erroneous operation probability of the driver under the normal operation of the system

P_{m2}: Erroneous operation probability of the driver under the false operation of the system who caused erroneous operation before introducing the system

P_{m3}: Erroneous operation probability of the driver under the false operation of the system who did not cause erroneous operation before introducing the system

Integrated erroneous operation probability after introducing the cooperative information system is shown as below.

$$P_{ms}^{(i)} = P_{m1} \times (1 - P_s) + P_s \times (P_{m2} + P_{m3})$$

When considering the effectiveness of the system, the reduced erroneous operation probability(ΔP_m) is shown as below because the driver's erroneous operation probability before introducing the system is P_m.

$$\Delta P_m = P_m - P_{ms}^{(i)}$$

Next, the accident reduction ratio (E) is shown as below.

$$E = 1 - \frac{P_{ms}^{(i)}}{P_m}$$

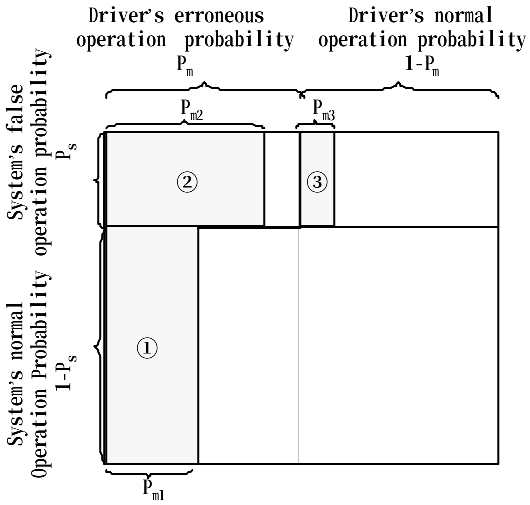

Figure 12 Driver-system integrated error probability model

Test Result Under False System Operation

Table 3 shows the summary of the evaluation results under the false operation of the system including the result without information (i.e. before introducing the system). In this case the false information means that the system informs the driver that there is not an obstacle even though there is an obstacle. The results are shown below.

- Eleven drivers out of the twenty subject drivers caused collision because the instructed vehicle speed is 120km/h on the straight course.
- About fifteen percent drivers out of drivers who caused collision without information do not utilize the obstacle information.
- The drivers who caused collision on false information are included in drivers who caused collision without information.
- Only one driver who did not cause a collision without information caused a collision under false information.

Table 3 Test result under false information

Information	The number of the driver who caused collision	Note
Without information (Base data)	11	Collision rate is high because the instructed vehicle speed is 120km/h on the straight course. The number of the subject driver is twenty.
With information	Average 1.5	Average of the number of collision of each information type. The result shows that about fifteen percent drivers out of drivers who caused collision without information do not utilize the obstacle information even when supported with the system.
False information	9	Drivers who caused collision on false information are included in drivers who caused collision without information.
False information	1	Only one driver who did not cause a collision without information caused a collision under false information.

Safety Analysis

Effectiveness Of The System The test result under false system operation is applied to the driver-system integrated erroneous operation model.

$P_{m1} = 0.14 \times P_m$

$P_{m2} = 0.8 \times P_m$

$P_{m3} = 0.09 \times P_m$

Therefore,

$$P_{ms}^{(i)} = P_{m1} \times (1 - P_s) + P_s \times (P_{m2} + P_{m3})$$
$$= 0.14 \times P_m + 0.75 \times P_s \times P_m$$

Consequently,

$$E = 1 - \frac{P_{ms}^{(i)}}{P_m}$$
$$= 0.86 - 0.75 \times P_s$$

When the false operation probability of the system is very small, the accident reduction ratio is 86%.

Risk Of The System When evaluating the risk of the system, we have to define it first.

Every system introduced in the real world has advantage and disadvantage. And it is seemed that we accept the system when the ratio between advantage and disadvantage is very small. For example, disadvantage/advantage is less than a value X.

When introducing the system, the reduced erroneous operation probability(ΔP_m) is secured. But under the false operation of the system, the driver-system integrated erroneous operation probability $P_s \times (P_{m2} + P_{m3})$ occurs. The risk ratio R is derived as below.

$$R = \frac{P_s \times (P_{m2} + P_{m3})}{P_m - (P_{m1} \times (1 - P_s) + P_s \times (P_{m2} + P_{m3}))}$$

Test result is applied.

$$R = \frac{0.89 \times P_s}{0.86 - 0.75 \times P_s}$$

Unfortunately acceptable value is not agreed in the society. If the false operation probability of the system is 10^{-3},

$R = 1.03 \times 10^{-3}$

The smaller value R is better. But, higher cost is necessary to improve the false operation probability. We think that in the case of information/warning systems R is between 10^{-2} and 10^{-3} because the driver has responsibility for driving.

CONCLUSION

Effectiveness of the forward obstacles collision warning system was evaluated. As a new evaluation criteria the speed at 100m ahead the obstacle was introduced, which is able to show the difference of effectiveness of each type of information more clearly. The evaluation result shows that the system using the combined information with the in-vehicle and the roadside information is effective. Next, as a new evaluation method for system risk the driver-system integrated erroneous operation probability model was introduced. The result shows that the accident reduction ratio is 86%.

REFERENCES

(1) T.Wakasugi, K.Yamada, 'DRIVER REACTION TIME TO FORWARD VEHICLE COLLISION WARNING', Proc. of ITS World Congress 2000